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Proton Beam Pumping of High Pressure Gas Lasers

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Plasma Physics Division

May 1977

NAVAL RESEARCH LABORATORY
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The application of proton beams to excite lasers, from gaseous elements under high pressure is proposed. It is pointed out that, using proton beams, higher laser power density can be obtained compared with current e-beam exctied lasers.

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CONTENTS

PROTON BEAM PUMPING OF HIGH PRESSURE GAS LASERS

INTRODUCTION

The advent [1-3] of relativistic electron beams, with high current density and short pulse durations ($\tau \leq 20$ nsec), have added a high power source for a variety of research in physics. It was inevitable and almost natural that e-beams will be utilized for the excitation of pulsed lasers. In (1971), e-beams were used in gaseous nitrogen for the first time[4] to produce the well known [5-7] nitrogen laser at 3371 Å. Many other lasers, as nitrogen and hydrogen lasers, excited in high current discharges,[8,9] were also reproduced by the application of e-beams.[10-12]

However, the applications of e-beams in liquid[13] and gaseous[14] Xenon under high pressure (> atmosphere) opened up a new era in the production of new lasers. This has led to excimer, [13-15] energy exchange,[16,17] and charge exchange[18,19] lasers. These lasers have a unique common denominator; they all depend on the number of atomic ions produced as the e-beam traverses the gaseous medium. Therefore, in principle, the more ionization is produced, the higher will be the laser power output. A linear extrapolation of this statement can only be tolerated to a degree when the number of the free electrons do not affect adversely the laser power output. An analysis, however, can be made for each case.

In this paper we propose the application of proton beams (p-beams) to excite high power lasers from rare gases under high pressure. The proton beams are expected to generate higher laser power outputs from excimer,[14,15] energy exchange[16,17] and charge exchange lasers[18,19] in comparison with excitations by e-beams. It should be noted that e-beams used for laser productions are generally in (0.5 - 1 MeV) energy range. This should be compared with current proton beams which have similar energies. Protons and electrons of the same energy ionize atomic

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species with extremely different ionization probabilities. The ionization cross section of atoms by protons are much larger than the ionization cross sections by electrons with energies equivalent to that of protons. This leads to higher stopping powers for gases towards protons and correspondingly higher number of ion pairs. For this reason one would expect higher power outputs from the previously mentioned lasers by the application of proton beams.

THE ELECTRON AND THE PROTON IMPACT IONIZATION CROSS SECTION OF ATOMS

In the limit of high velocity (Born Approximation) the total ionization cross section for atoms, in proton impact is equal to that by electron impact at the same velocity. This has been predicted theoretically [21,22] and comparisons[23,24] of experimentally measured cross sections with theory have been confirmed for several gases. Figures 1-3 show experimental data[25] for the ionization cross section of He, A and Ne by protons and electrons of equal velocity. These figures indicate that ionization cross sections of atoms by protons, at higher energies, can be obtained from the available data for electrons with equal velocity. For higher energies, beyond experimentally available region, one can use the Born approximation to obtain the ionization cross sections of atoms by electrons. Using this approach, for example, one finds that the ionization cross section of He by 1 MeV electrons is $\sim 3 \times 10^{-20}$ cm^2. We consider p-beams[20] with 0.3 MeV energy for applications to excite lasers in gases under high pressure. These protons ionize He with an ionization cross section of $\sim 6 \times 10^{-17}$ cm^2 which is quite large in comparison with that for 1 MeV electrons.

THE STOPPING POWER OF GASES FOR ELECTRONS AND PROTONS

Charged particles with energies, E, of few MeV lose energy, as they traverse gaseous medium, by ionization and excitation of the atomic and ionic species. The amount of energy they deposit in each atomic gas depends on the stopping power, L(E), of these atoms for the charged particles. Furthermore, the amount of energy expended per ion pair, W, is practically a constant characteristic of the atom. Therefore, with a knowledge of L(E) and W one can calculate the number of ions produced

per unit volume. The stopping power can be obtained by calculation using Bethe approximation or from experimental data. Figure 4 shows the stopping power of He for protons where both calculated and experimental data indicate that at higher energies Bethe's approximation is very good.

For protons with velocity V the stopping power[26] can be calculated using

$$L(E) = \frac{4\pi e^4}{mV^2} B, \tag{1}$$

where

$$B = Z \log \frac{2\, mV^2}{I}. \tag{2}$$

Here Z is the charge of the atomic gas and I an average excitation energy of the atom (I = 40 eV for He) while e and m have their usual meaning. For relativistic electrons, on the other hand, the stopping power[26] is

$$L(E) = \frac{2\pi e^4}{mV^2} Z \left\{ \log \frac{mV^2 E}{2\, I^2(1-\beta^2)} - \left(2\sqrt{1-\beta^2} - 1 + \beta^2\right) \log 2 \right.$$
$$\left. + 1 - \beta^2 + \frac{1}{8}\left(1 - \sqrt{1-\beta^2}\right)^2 \right\}. \tag{3}$$

In Eq. (3), β is V/c and E is the kinetic energy of the electron. From Fig. 4 we see that the stopping power of He for 0.3 MeV protons is $\sim 6 \times 10^{-15}$ (eV - cm^2). Using Eq. (3), the stopping power of He for 1 MeV electrons is 10^{-18} (eV - cm^2). Obviously protons of 0.3 MeV energy make more ion in He per unit path than electrons of 1 MeV. The energy deposited per unit path can be calculated from the stopping power according to

$$\frac{dE}{dx} = -N_o L(E), \tag{4}$$

where N_o is the density of the atomic gas.

E-BEAM PRODUCED LASERS FROM RARE GASES UNDER HIGH PRESSURE

Three kinds of lasers have been produced in high pressure rare gases by the application of high energy e-beams. These are excimer,[13,14] energy exchange,[16,17] and charge exchange[18,19] lasers. As stated earlier, these lasers depend from the outset on the number of atomic ions produced by the passage of the e-beam. The atomic ion in all of these lasers is transferred into a molecular ion. For excimer and energy exchange lasers these molecular ions are dissociatively recombine with the free electrons producing atoms in excited metastable and ground states. In the case of the excimer lasers these metastable states in collisions with atom in the ground state, with the presence of a third body from an excited molecular state which is the upper laser level. In the case of energy exchange lasers, however, the metastable atomic state resonantly energy exchanges with a minor molecular species in the gaseous mixture to form the upper laser level. However, in charge exchange lasers, the molecular ion resonantly charge exchanges with a minor molecular species to form the upper laser level. The general kinetics of these lasers will be outlined below:

A. <u>Excimer Laser from Xenon</u>

$$e + Xe \rightarrow Xe^+ + 2\,e \tag{5}$$

$$Xe^+ + Xe + Xe \rightarrow Xe_2^+ + Xe \tag{6}$$

$$Xe_2^+ + e \rightarrow Xe^* + Xe \tag{7}$$

$$Xe^* + Xe + Xe \rightarrow Xe_2^* + Xe \tag{8}$$

B. <u>Energy Exchange Laser in Ar - N_2 Mixture ($Ar >> N_2$)</u>

$$e + Ar \rightarrow Ar^+ + 2\,e \tag{9}$$

$$Ar^+ + Ar + Ar \rightarrow Ar_2^+ + Ar \tag{10}$$

$$Ar_2^+ + e \rightarrow Ar^* + Ar \qquad (11)$$

$$Ar^* + N_2 \rightarrow N_2^* + Ar \qquad (12)$$

C. <u>Charge Exchange Laser in He - N_2 Mixture ($He \gg N_2$)</u>

$$e + He \rightarrow He^+ + 2\,e \qquad (13)$$

$$He^+ + He + He \rightarrow He_2^+ + He \qquad (14)$$

$$He_2^+ + N_2 \rightarrow (N_2^+)^* + He + He \qquad (15)$$

The ionization step in these equations can be realized with protons as well, other kinetics may arise with the presence of protons and a detail study should be made in each case.

We propose the application of proton beams[20] (0.3 - 1 MeV) to excite $He_2^+ + N_2$ charge exchange laser as a first step towards proton beam excited laser. In addition to the kinetics of this laser outlined in Eqs. (13) - (15) two other processes will also occur. That is

$$H^+ + He \rightarrow H + He^+ \qquad (16)$$

and

$$H + He \rightarrow H^+ + He + e \qquad (17)$$

At velocities of interest, these two processes have cross section[27] of 10^{-18} cm^2 and 5×10^{-17} cm^2, respectively. This indicates that the proton fraction in the beam will be 50/51 compared to 1/51 for hydrogen atom. Thus one may ignore this effect. However, the collisional effects on the laser levels by the free electrons must be considered as the electron density increases in addition to their recombination with the ions. This is necessary for obtaining the optimum condition for the power output.

A COMPARISON OF A PROTON AND AN ELECTRON BEAM DEVICE

This report advocates the application of p-beams for excitation of a variety of lasers. The Plasma Physics Division has several proton-beam devices[20] which vary in terms of their particle energies. All these devices, in principle, can be utilized for laser excitations. However, we shall make a comparison between the lowest energy (0.3 - 0.4 MeV) proton beam device with a 1 MeV electron beam[28] used for $He_2^+ + N_2$ charge exchange laser. The lowest energy proton beams at NRL are produced from SOL e-beam device by employing a reflex triode.[20] The characteristics of these two devices are given in Table 1.

Table 1

	p-Beam	e-Beam
Energy	0.3 - 0.4 MeV	1 MeV
Current Density	0.14 (kA/cm^2)	1.3 (kA/cm^2)
Pulse Width	30-50 (nsec)	20 (nsec)

The comparison in Table 1 shows that the current density is higher in the e-beam in comparison with the p-beam. However, the number of ions produced by the proton beam in He is much higher than that by the e-beam. A judicious application of this proton beam with the appropriate gas mixtures will give laser power densities one to two orders of magnitude higher than the e-beam device. Higher energy proton beams can be used to excite larger volumes of gaseous mixtures and hence result in higher total power outputs.

Since the charge exchange laser from $He_2^+ - N_2$ is in the visible, the application of the proton beam to produce it should be routine.

REFERENCE

1. S. E. Graybill and S. V. Nablo, Appl. Phys. Lett. 8, 18 (1966).

2. W. T. Link, IEEE Trans. Nucl. Sci. 14, 777 (1967).

3. F. M. Charbonnier, J. P. Barhous, J. L. Brewster, W. P. Dyke, and F. J. Grundhauser, IEEE, Trans. Nucl. Sci. 14, 789 (1967).

4. M. Clerc and M. Schmidt, C. R. Acad. Sci. B272, 668 (1971).

5. D. A. Leonard, Appl. Phys. Lett. 7, 4 (1965).

6. J. D. Shipman Jr., Appl. Phys. Lett. 10, 3 (1967).

7. A. W. Ali, A. C. Kolb and A. D. Anderson, Appl Opt. 6, 2115 (1967).

8. R. W. Waynant, J. D. Shipman, Jr., R. C. Elton, and A. W. Ali, Appl. Phys. Lett. 17, 383 (1970).

9. R. T. Hodgson, Phys. Rev. Lett. 25, 494 (1970).

10. R. W. Dreyfus and R. T. Hodgson, Appl. Phys. Lett. 20, 195 (1972).

11. E. L. Patterson, J. B. Gerardo and A. Wayne Johnson, Appl. Phys. Lett. 21, 293 (1972).

12. R. T. Hodgson and R. W. Dreyfus, Phys. Rev. Lett. 28, 536 (1972).

13. N. G. Basov, V. A. Danilychev, and Yu. M. Popov, Soviet J. Quant. Elect. 1, 18 (1971).

14. H. A. Koehler, L. J. Ferderber, D. L. Redhead, P. J. Ebert, Appl. Phys. Lett. 21, 198 (1972).

15. H. A. Koehler, L. J. Ferderber, D. L. Redhead, and P. J. Ebert, Phys. Rev. A9, 768 (1974) IBID A12, 968 (1975).

REFERENCE (cont.)

16. S. K. Searles and G. A. Hart, Appl. Phys. Lett. 25, 79 (1974).

17. N. G. Basov, A. N. Brunin, V. A. Danilychev, V. A. Dolgikh, O. M. Kerimov, A. N. Lobanov, S. I. Sagitov, and A. F. Suchkov, Sov. J. Quant. Elect. 5, 1218 (1975).

18. C. B. Collins and A. J. Cunningham, S. M. Curry, B. W. Johnson, and M. Stockton, Appl. Phys. Lett. 24, 477 (1974).

19. N. G. Basov, L. A. Vasilev, V. A. Danilychev, G. G. Dolgov-Savelev, V. A. Dolgikh, O. M. Kerimov, L. L. Kozorovitskii, V. K. Orlov and D. D. Khodkevich, Sov. J. Quant. Elect. 5, 869 (1975).

20. J. Golden, C. A. Kapetanakos, S. J. Marsh and S. J. Stephanakis, Phys. Rev. Letts. 38, 1301 (1977) and references therein for other proton beam devices.

21. D. R. Bates and G. Griffing, Proc. Phys. Soc. A66, 961 (1953).

22. R. A. Mapelton, Phys. Rev. 109, 1166 (1958).

23. F. J. DeHeer, J. Schutten and H. Monstafa, Physica 32, 1766 (1966).

24. J. W. Hooper, D. S. Harmer, D. W. Martin and E. W. McDaniel, Phys. Rev. 125, 2000 (1962).

25. E. W. McDaniel, "Collision Phenomena in Ionized Gases," John Wiley and Sons Inc. New York (1964).

26. A. Dalgarno, Chapt. 15 in "Atomic and Molecular Processes" Bates Ed. Academic Press, New York (1962).

27. S. C. Brown "Basic Data of Plasma Physics," The MIT Press, Cambridge, Mass. (1966).

28. C. B. Collins and A.J. Cunningham, Appl. Phys. Lett. 27, 127 (1975).

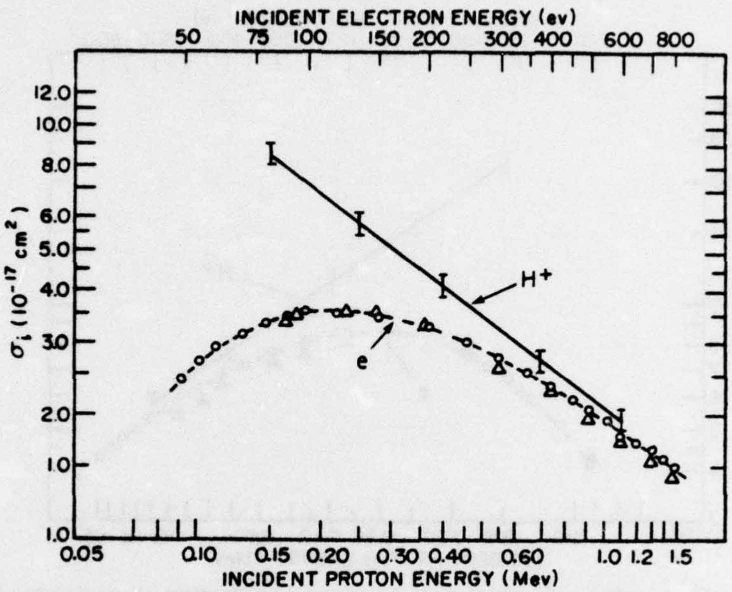

Fig. 1 — Comparison of experimental apparent ionization cross sections for protons and electrons of equal velocity incident on helium. (Data compiled in Ref. 25.)

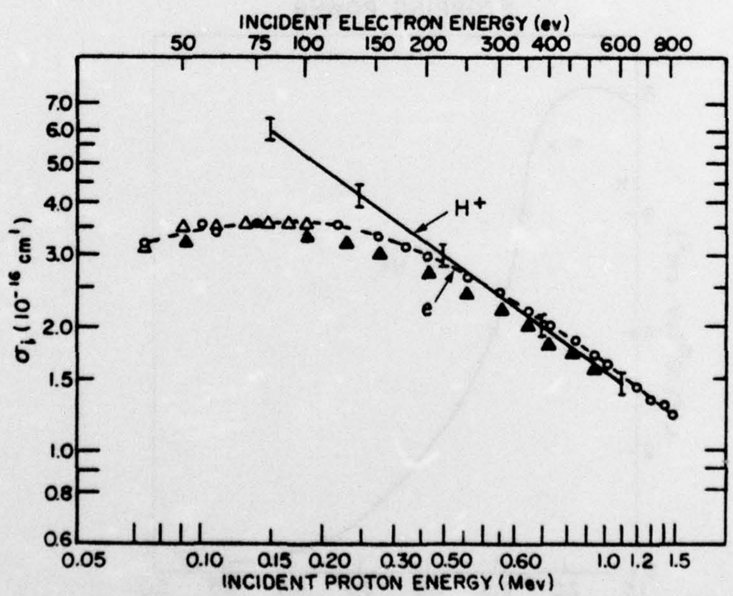

Fig. 2 — Comparison of experimental apparent ionization cross sections for protons and electrons of equal velocity incident on argon. (Data compiled in Ref. 25.)

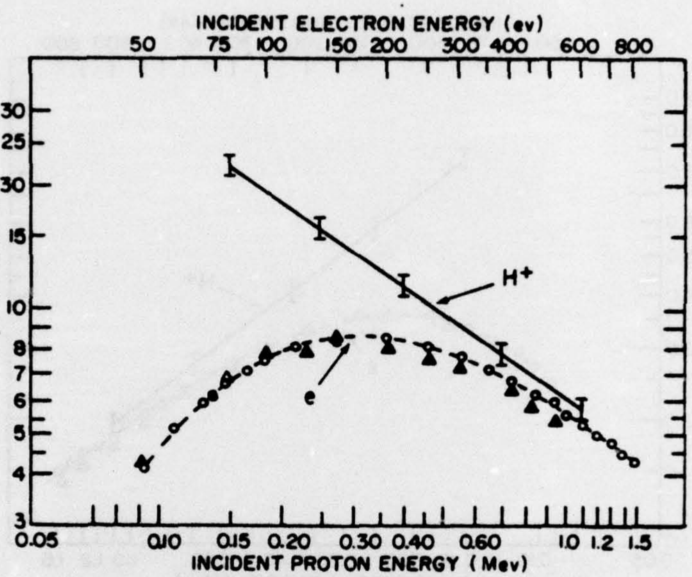

Fig. 3 — Comparison of experimental apparent ionization cross sections for protons and electrons of equal velocity incident on neon. (Data compiled in Ref. 25.)

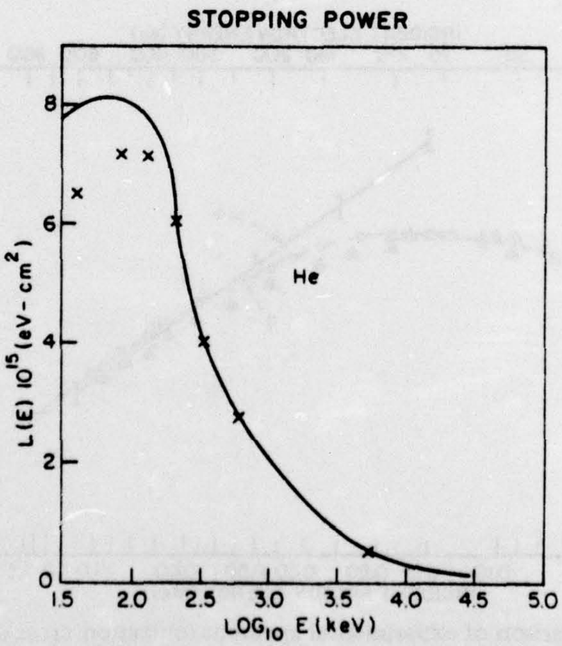

Fig. 4 — Calculated and experimental stopping power of He for protons. (From Ref. 26.)